Landscape and Urban Planning xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan

Characterizing behavioral adaptation to climate change in temperate forests

Alexandra Paige Fischer

School for Environment and Sustainability, University of Michigan, 440 Church Street, Ann Arbor, MI 48109, United States

A B S T R A C T

The potential impacts of climate change on terrestrial ecosystems are well recognized, and a wide variety of adaptation measures have been proposed. However, little is known about whether and how adaptation is occurring among people in these ecosystems. Understanding adaptation at the level of individuals, including members of households and extended families, is especially important because it is the level at which people most directly experience climate change impacts and engage in behavioral change. I offer a framework for characterizing the responses of individual landowners to climate change impacts in terms of adaptation behavior, and distinguishing adaptation from coping. The framework expands existing typologies of adaptation behavior to include a hierarchy of three analytical units of behavior: activities, practices, and strategies. I illustrate the framework by applying it to landowners' responses to climate change impacts in temperate forests, a biome that is undergoing dramatic change. Individuals own and rely on large proportions of land in many temperate forest countries and are therefore exposed and sensitive to climate change impacts. Through management, they also influence how forests and their own well-being are affected by climate change. By improving characterizations of behavioral responses to climate change, the framework I propose can help researchers and practitioners evaluate progress toward adaptation with greater rigor.

1. Introduction

Climate change is one of the world's most pressing challenges, one that will require society to live with new—and in some cases more hazardous—environmental conditions. Understanding whether and how people adapt to climate change is critical to society's ability to design and evaluate adaptation policies and plans. Understanding adaptation among individuals is especially important because it is at the individual level that people most directly experience climate change impacts and engage in behavioral change. For example, individual landowners, including members of households and extended families, are often highly interdependent with the ecological systems that they manage, directly depending on their home sites, farms, forests, and ranches for shelter, food, water, and fiber. The ways in which people manage their land in response to past climate impacts influence the vulnerability of ecosystem goods and services to future impacts, which in turn affects their own well-being and need to adapt (Birkmann, 2011).

Enabling and incentivizing adaptation has become a major policy goal around the world. However, despite a wealth of theories and frameworks for characterizing adaptation (e.g., Bassett & Fogelman, 2013; Smit, Burton, Klein, & Wandel, 2000; Wise et al., 2014), understanding of how to evaluate adaptation at the individual level is limited (Ford & Berrang-Ford, 2016; Woodruff & Stults, 2016). At present, efforts to track adaptation lack consistency, comparability, comprehensiveness, and coherence (Ford & Berrang-Ford, 2016). Policy and research efforts define adaptation differently, draw on data at incomparable units of observation (e.g., individual, vs. community), have limited access to data sets, and employ indicators that often do not reflect substantive adaptation (Ford & Berrang-Ford, 2016). As such, these research and policy efforts risk conflating long term behavioral changes that improve future suitability to the environment ("adaptation") with short-term responses to ward off immediate adverse impacts (often termed "coping"). This ambiguity can render such efforts inefficient and potentially counterproductive by making it difficult to evaluate whether adaptation (or coping) has occurred. For these reasons, scholars and practitioners alike have called for more rigorous approaches to characterizing, monitoring, and evaluating adaptation, with the argument that clearer conceptual frameworks and more standardized and generalizable research will increase scientific understanding (Ford & Berrang-Ford, 2016).

Here I offer a framework for characterizing individual responses to climate change in terms of adaptation behavior. The framework expands existing typologies of adaptation behavior to include a hierarchy of three analytical units of behavior: activities, practices, and strategies. It provides a structure for classifying climate change responses along multiple dimensions and at multiple levels of specificity that would make characterizing adaptation behavior more consistent, coherent, and comparable. As background, I begin by reviewing typologies of adaptation behavior that have been developed in fields such as human geography, as well as empirical research papers that apply elements of these typologies to investigations of behavioral responses to climate change among individuals. I also review the empirical literature on behavioral responses to climate change impacts on temperate forests,

E-mail address: apfisch@umich.edu.

https://doi.org/10.1016/j.landurbplan.2018.09.024
Received 14 November 2017; Received in revised form 3 July 2018; Accepted 27 September 2018
0169-2046/ © 2018 Elsevier B.V. All rights reserved.

ARTICLE IN PRESS

specifically, and discuss the unique challenges that forests present to distinguishing between adaptation and coping. I focus on temperate forests because they are a biome that is projected to experience a multitude of severe climate change impacts (Millar & Stephenson, 2015; Seidl et al., 2017) and because they are owned and managed to a large extent by individuals—50% in the USA and Europe (Butler & Leatherberry, 2004; Forest Europe, 2011). Finally, I describe the framework and illustrate it with examples of management in temperate forests by individuals, although the framework can be adapted to other ecological systems (e.g., farms, rangelands, and urban areas) and other levels of social organization (e.g., organizations). I conclude by offering suggestions for how to increase the rigor of scholarly and policy efforts to understand adaptation.

2. Current frameworks for characterizing adaptation behavior

Several theoretical typologies of adaptation behavior provide guidance for considering adaptation at the level of individuals. One broad typology distinguishes adaptation from other behavioral responses to climate change (Fazey et al., 2010; Smit & Wandel, 2006). Although a wide variety of definitions are currently used in research and practice, adaptation tends to be viewed as a long-term shift in behavior that reduces adverse impacts of environmental change, enables people to take advantage of opportunities, and increases people's suitability for their environment (Denevan, 1983; McCarthy et al., 2001; Nelson, Adger, & Brown, 2007; Parry, M. L., Canziani, O. F., Palutikof, J. P., & Hanson, 2007; Smit, Burton, Klein, & Street, 1999). Adaptation, in this sense, can be distinguished from other types of behavioral responses to climate change. Coping, for example, refers to short-term efforts to mitigate shocks and stresses and regain stability (Blaikie, Cannon, Davis, & Wisner, 1994; Fazey et al., 2010; Opiyo, Wasonga, Nyangito, Schilling, & Munang, 2015). Coping can also entail manipulation of an external system to make self-regulation unnecessary (Thomsen, Smith, & Keys, 2012). Maladaptation, on the other hand, refers to efforts to adapt that increase the vulnerability of oneself and others (Barnett & O'Neill, 2010; Juhola, Glaas, Linnér, & Neset, 2016).

Other theoretical typologies distinguish behavioral responses to climate change on the basis of key attributes (Table 1), such as how purposeful or deliberate they are (e.g., enacted autonomously as part of daily life, at one extreme, versus planned, at the other), their timing (e.g., how reactive or proactive they are relative to the climate change impact), and their scope (e.g., the extent to which they constitute incremental versus transformational change) (Fankhauser, Smith, & Tol, 1999; Kates, Travis, & Wilbanks, 2012; Nelson et al., 2007; Pelling, O'Brien, & Matyas, 2015; Smit et al., 2000). The emerging literature on adaptation in the field of forestry also distinguishes between behaviors on the basis of their underlying goals with regard to managing change (e.g., whether people aim to resist change, be resilient to change, or transition to new conditions) (Janowiak et al., 2014; Millar, Stephenson, & Stephens, 2007), although there is some debate about whether resilience and resistance can be considered adaptation goals (Nelson, 2011).

A number of empirical studies employ attributes from theoretical adaptation behavior typologies to describe climate change responses among forest, farm, ranch, and residential landowners—for example, studies by Below et al. (2012); Esham and Garforth (2013); Raymond and Robinson (2013); Wheeler, Zuo, and Bjornlund (2013); Zheng and Dallimer (2016), Lopez-Marrero (2010), Wamsler and Brink (2014), van Gameren and Zaccai (2015), and Grothmann and Patt (2005). With the exception of Fischer (in press) and Wamsler and Brink (2014), these studies refer to all responses as adaptation (i.e., do not distinguish adaptation from coping), and they primarily characterize responses as autonomous, reactive, and incremental. Several of the studies classify responses according to typologies. In a study of flood-prone coastal areas, for example, Lopez-Marrero (2010) distinguishes between tactical and strategic responses to flooding by homeowners, drawing on Smit et al. (1999). The Lopez-Marrero (2010) study uses "strategic responses" to refer to long-term strategies that involve access to material, technological, economic, and institutional resources, and "tactical responses" to refer to short-term actions undertaken shortly before or during hazard occurrences. In a study of urban homeowners, Wamsler and Brink (2014) distinguish explicitly between coping practices and adaptive practices on the basis of their timing (e.g., well in advance, shortly before, during, and following hazard impacts) and objectives (e.g., hazard reduction and avoidance, vulnerability reduction, preparedness for response, and preparedness for recovery). Wamsler and Brink (2014) also distinguish between practices that are planned versus unplanned, intentional versus unintentional, and autonomous versus supported by formal institutions. In the context of forests, Fischer (in press) classifies individual landowners' management strategies in terms of purposefulness, timing, and scope. van Gameren and Zaccai (2015) classify individual forestland owners on the basis of whether they undertake planned (as opposed to unplanned) adaptive actions and aim to increase resilience (as opposed to not adapting).

Although studies such as these contribute to scientific understanding of behavioral adaptation to climate change at the individual level, as a body of scholarship, they do not classify behavioral responses to climate change in consistent ways, potentially limiting the comparability and coherence of adaptation research (Ford & Berrang-Ford, 2016). For example, some of the behaviors that Lopez-Marrero (2010) refer to as adaptation strategies—purchasing water resistant furniture and rebuilding houses with water resistant materials—are behaviors that people could undertake for any number of reasons; only when the purpose of these activities is made clear (i.e., to mitigate future flood hazards) is it apparent that they should be considered adaptation behaviors. Similarly, the crop management, land management, and irrigation management measures described by Esham and Garforth (2013) are broad sets of agricultural activities; to consider them adaptation measures, additional information about their purpose (i.e., to mitigate drought and flooding) would be needed. On the other hand, growing vegetation to reduce landslides and growing vegetation to mitigate urban heat island effects, as described by Wamsler and Brink (2014), have clear purposes. As such, they are considered adaptation practices.

3. The need for a systematic approach to characterizing behavioral adaptation in temperate forests

Temperate forests and the individuals who manage these forests are highly vulnerable to climate change impacts. Increasing temperatures and alterations in precipitation patterns are expected to expose temperate forests to severe stress and disturbances, such as large-scale droughts, insect and disease infestations, and wildfires, which could ultimately change forest structure and composition and reduce the growth and survival of some forest types and tree species (Allen et al., 2010; Chmura et al., 2011; Dukes et al., 2009; Fettig et al., 2013; Flannigan et al., 2013; Hayhoe, VanDorn, Croley Ii, Schlegal, & Wuebbles, 2010; Hubbart, Guyette, & Muzika, 2016; Millar & Stephenson, 2015). As long-lived organisms with relatively slow rates of migration, temperate tree species may be particularly sensitive to these impacts (Fettig et al., 2013; Kolström et al., 2011; Schoene & Bernier, 2012).

Individual landowners in the temperate forest biome are exposed and sensitive to these impacts because they manage a substantial proportion of forestland area and rely on the ecosystem goods and services those forestlands provide (Fischer & Frazier, 2018). Wildfires, storms, droughts, and pest and disease outbreaks may degrade forest health and threaten property and timber values on lands owned by individuals. Wildfires, in particular, may directly threaten human life, as well as human health, by releasing into the atmosphere particulates that are harmful to humans (Liu, Pereira, Uhl, Bravo, & Bell, 2015). Declines in certain tree species, such as some economically important oak and conifer species (Gómez-Mendoza & Galicia, 2010; Hanewinkel,

ARTICLE IN PRESS

Table 1
Dimensions of theoretical adaptation typologies and their attributes.

	Attribute	Description	Forestry examples
Purposefulness	Autonomous	Entails ongoing implementation of existing knowledge and techniques in response to experienced climate change (Birkmann, 2011; Smit et al., 2000).	Thin to reduce drought stress; construct breaks in vegetation to prevent spread of wildfires, pests, and diseases (Schoene & Bernier, 2012).
	Planned	Entails creation of new knowledge and techniques, and mobilizing institutions and policies to build or strengthen technologies and infrastructure, often as a result of policy intervention (Birkmann, 2011; Smit et al., 2000).	Favor species and genotypes that are expected to be better suited for future conditions, such as those with wide moisture and temperature tolerances (Janowiak et al., 2014; Schoene & Bernier, 2012).
Timing	Proactive	Entails behavioral change to reduce future damage, risk and vulnerability, often through planning, monitoring, increasing awareness, building partnerships, and enhancing learning or research (Berrang-Ford, Ford, & Paterson, 2011; Smit et al., 2000).	Insure forest property against potential future losses; transition to species or stand structures that are better adapted to projected future conditions; experiment with new forest management practices (Millar et al., 2007; Ogden & Innes, 2008).
	Reactive	Entails immediate behavioral response to regain stability, often through spreading risk and securing resources (Berrang-Ford et al., 2011; Smit et al., 2000).	Harvest stands following disturbance events of unexpected magnitude, severity or intensity to salvage value and replant (Ogden & Innes, 2008).
Scope	Incremental	Entails making small changes in current contexts to avoid disruptions and continuing to pursue the same objectives (Kates et al., 2012; Park et al., 2012).	Shorten rotation intervals to reduce the probability of loss to storm events (Kolström et al., 2011; Schoene & Bernier, 2012; Spittlehouse & Stewart, 2003); diversify species to spread risk; thin to reduce density and susceptibility of forest stands to stress (Keenan, 2015; Millar et al., 2007).
	Transformational	Entails making changes at large scales or that are new to a particular region or system; changing the broader biophysical, social, or economic system (Kates et al., 2012; Park et al., 2012; Pelling et al., 2015).	Coordinate efforts to reduce spread of wildfire, pests, and diseases across ownerships; create new infrastructure for preserving timber harvested in the aftermath of disease and pest outbreaks; extend time horizons of management (Kolström et al., 2011; Spies et al., 2010); plant species from warmer climate rather than using local seedlings (Millar et al., 2007).
Goal	Resistance	Buffer or protect from change; take measures to preserve stability and resist change (Pelling et al., 2015).	Create refugia for rare species; protect forests from severe fire and wind disturbance; alter forest structure to reduce severity or extent of wind and ice damage; establish breaks in vegetation to dampen spread of pests, diseases, and wildfire (Janowiak et al., 2014; Millar et al., 2007).
	Resilience	Promote the return to normal conditions after disturbances to preserve system integrity when conditions change (Carpenter, Walker, Anderies, & Abel, 2001; Nelson et al., 2007; Pelling et al., 2015; Walker et al., 2002).	Increase ecosystem redundancy across landscapes; favor existing genotypes that are better adapted to future conditions; use landscape-scale planning and partnerships to reduce fragmentation and enhance connectivity; restore fire to fire-adapted ecosystems; maintain and restore diversity of native tree species (Janowiak et al., 2014; Millar et al., 2007).
	Transition	Actively facilitate or accommodate change; undertake measures that challenge the stability of current systems (Lin & Petersen, 2013; Pelling et al., 2015).	Facilitate species migration; establish or encourage new mixes of native species; cultivate drought- and heat-tolerant species and populations (Janowiak et al., 2014; Millar et al., 2007).

Cullmann, Schelhaas, Nabuurs, & Zimmermann, 2013; Jonsson, Appelberg, Harding, & Bärring, 2009; Keenan, 2015; Peltola, Kellomäki, & Väisänen, 1999), may challenge forestry operations for many landowners (Irland et al., 2001; Lal, Alavalapati, & Mercer, 2011). In addition, increased cloudiness may reduce productivity, and warmer, wetter conditions may complicate thinning, harvesting, and other forest management activities (Maracchi, Sirotenko, & Bindi, 2005). As a result, landowners may experience declining profits and land values (Maracchi et al., 2005). Climate change may also create opportunities for landowners in some areas. For example, in far eastern deciduous forests and far western coniferous forests of the USA, where growth is currently limited by cold, elevated carbon dioxide levels and warmer temperatures may increase growth and productivity in areas with adequate moisture (Bachelet et al., 2003; Chmura et al., 2011). As conditions on forestlands change, some forest management practices will no longer be viable, making new approaches necessary (Irland et al., 2001)—thus the need to respond and, if possible, adapt.

Recognizing that climate change will increasingly impact forestlands owned by individuals, natural resource agencies have developed policies and outreach programs to help landowners reduce adverse impacts and take advantage of opportunities that changing conditions might bring. In the aftermath of a hurricane that felled millions of conifer trees in Sweden, for example, that country's Forest Agency encouraged forestland owners to reduce future vulnerability by harvesting on shorter rotations, increasing regeneration harvests, thinning at earlier points in time, and replanting with broadleaf species instead of spruce, which is susceptible to strong winds (Lidskog & Sjödin, 2014). Other countries have helped landowners mitigate adverse climate change impacts by promoting forest management to reduce wildfire risk and conserve water (Kolström et al., 2011; Reams, Haines, Renner, Wascom, & Kingre, 2005). In the USA, land management and landowner assistance agencies have developed education and technology transfer programs to help forestland owners adapt to climate impacts (Grotta, Creighton, Schnepf, & Kantor, 2013; Swanston, C. W. J., Maria, Brandt, L. A., Butler, P. R., Handler, S. D., & Shannon, 2016).

An emerging body of empirical research suggests that some individual forestland owners have responded to climate change impacts through alterations in forest management and planning behaviors. In terms of planning practices, owners have gathered information and advice to inform forest management decisions, monitored forests more closely for stress, and purchased insurance against damage (Eriksson, 2014; Fischer, in press; Sousa-Silva, Ponette, Verheyen, Van Herzele, & Muys, 2016; van Gameren & Zaccai, 2015). Regarding forest practices, owners have planted new species to establish mixed stands; cultivated species and varieties that are better adapted to changing site conditions; shifted the timing of planting, thinning, and pruning to ensure more favorable conditions for forestry operations; shortened rotations to reduce chances of loss to storms, wildfires, and other events; and thinned stands to reduce stress from drought and wind and to mitigate the risk of wildfire (Blennow, 2012; Eriksson, 2014; Fischer, in press; Lawrence & Marzano, 2014; Sousa-Silva et al., 2016; van Gameren & Zaccai, 2015).

Based on theoretical typologies, the practices that owners have undertaken in these studies largely compose strategies that reflect autonomous, rather than planned, responses to climate change. Owners have employed experience-based, practical, and embodied knowledge over theoretical knowledge (e.g., projected climate change impacts) when making decisions (van Gameren & Zaccai, 2015), and they have implemented existing knowledge and techniques to reduce the vulnerability of their forests to stressors. For example, they have diversified species and shortened harvest rotations to reduce the chance of singular losses to storms, droughts, and diseases, and they have performed forestry activities earlier in the winter to avoid having their access to the forest prevented by early thaws (Blennow, Persson, Tomé, & Hanewinkel, 2012; Eriksson, 2014; Fischer, in press; Sousa-Silva et al., 2016; van Gameren & Zaccai, 2015). Studies have not provided evidence of owners creating new knowledge and techniques or mobilizing institutions and policies to create new technologies or infrastructure.

Both proactive and reactive adaptations are evident in studies of individual forestland owners (Eriksson, 2014; Fischer, in press), although studies more frequently document reactive approaches, such harvesting and replanting trees damaged by wildfires, pest and disease incursions, or wind events (Lidskog & Sjödin, 2014), than proactive approaches. Diversification of species, replacement of vulnerable species with more stress-tolerant species, adjusting stand structure through thinning, increasing spacing of seedlings to reduce susceptibility to future wind storms and drought, and purchasing insurance to mitigate potential losses are some examples of proactive forest management practices that forestland owners have used to respond to climate change (Blennow & Persson, 2009; Eriksson, 2014; Fischer, in press; Sousa-Silva et al., 2016; van Gameren & Zaccai, 2015). However, the proactive approach of experimentation has been absent from the literature on individual forestland owners, with the exception of one study in which landowners explored the cultivation of species from other regions (van Gameren & Zaccai, 2015).

Despite recognition of the potential benefits of managing stressed forests on large spatial scales and long time horizons and through coordination across organizational scales (Fischer, in press; van Gameren & Zaccai, 2015), the published literature does not document such transformational responses among individual forest landowners in response to climate change impacts. In fact, private landowners in a study in the Pacific Northwest region of the USA pointed out that adapting management practices for climate projections many decades in the future was at odds with the time scale of forest management that they were used to, which ranged from a few years to decades (Grotta et al., 2013). Instead, owners have made incremental changes to forest management, implementing management actions intended to avoid disruptions of systems at their current locations. Landowners have tended to use risk-spreading strategies, such as diversifying species to increase the chance of some species thriving under future conditions, thinning to reduce density and therefore the susceptibility of forest stands to stress, and shortening rotation intervals to reduce the probability of loss to storm events (Blennow et al., 2012; Eriksson, 2014; Fischer, in press; Lawrence & Marzano, 2014; Sousa-Silva et al., 2016; van Gameren & Zaccai, 2015). These responses encompass no-regrets actions that reduce the vulnerability of forests to climate variability and non-climate risks in general (van Gameren & Zaccai, 2015).

The three theoretical goals of adaptation—resistance, resilience, and transition—are evident, to some extent, in the literature on individual forestland owners. For example, owners have promoted a diversity of species and stand structures to improve their forests' ability to bounce back (i.e., be resilient) after storms, drought, and pest and disease outbreaks (Fischer, in press; van Gameren & Zaccai, 2015). Landowners have also engaged in management approaches that could accommodate changing growing conditions and stressors (i.e., enable transition), for example, by replacing tree species with other, more drought and storm hardy native and exotic tree species presumed to be better adapted to future climate conditions (Eriksson, 2014; van Gameren & Zaccai, 2015). More often, however, landowners have appeared to resist climate change impacts by protecting their forests and themselves from losses caused by storms, drought, and wildfires through thinning, early harvest and insurance (Eriksson, 2014), and by replanting with species with high values in current markets rather than potential future markets (Lawrence and Marzano 2014).

Although the empirical research on climate change adaptation among individual forestland owners suggests that owners are responding to climate change, it is difficult to judge whether owners' behavioral adjustments constitute long-term behavioral changes that increase their suitability to the environment or temporary adjustments that ward off immediate adverse impacts. In other words, with the exception of Fischer (in press), operational definitions of adaptation do not distinguish between adaptation in the strict sense and other forms of behavioral response, such as coping. Such distinctions are important in the context of temperate forests because many forest management activities can constitute either adaptation or coping depending on how they are used.

For example, thinning brush and small trees from forest stands are activities that individual landowners might use to manage forests in landscapes that are adapted to frequent, low-severity fire as a natural disturbance process (Fischer, 2011). But forestland owners may thin as part of routine forest management operations to reduce stress and increase vigor (autonomous), or as part of novel designs developed through global syntheses of research and practice (planned). Landowners may also thin after experiencing a fire and suddenly becoming aware of fire risk (reactive) or after educating themselves about the possibility of future fires in a warmer, drier climate (proactive). Landowners may thin more stands on their own properties in slightly different or more aggressive ways each year (incremental) or participate in large-scale coordinated efforts with other landowners to prepare a shared landscape for the reintroduction of fire as a natural disturbance process (transformational). Moreover, thinning is an activity that could be used to pursue multiple goals, some of which may be more adaptive than others. For example, landowners may thin to make stands of trees less prone to mortality during wildfires (resistance), minimize loss in the event of a fire so that stands can bounce back (resilience), or prepare forests for an era in which forest fires will occur more frequently and with greater severity (transition). Only when viewed collectively, will these attributes indicate whether landowners are thinning as part of long-term efforts to transition to an era of more frequent and severe wildfires (e.g., resetting conditions so fires can burn without catastrophic consequences) (adaptation) or as part of short-term efforts to minimize immediate adverse impacts (e.g., create conditions that make it easier to suppress fires from burning) (coping).

Further complicating distinctions between adaptation and other types of response, many forest management activities can exacerbate or ameliorate climate change impacts (i.e., be adaptive or maladaptive) depending on the spatial and temporal scale at which they are observed. By suppressing fires, for example, a landowner may protect his or her own parcel but also allow flammable vegetation to continue to accumulate on that parcel, creating a fire hazard that, if ignited, could spread to adjacent lands and adversely affect neighbors (maladaptation). Similarly, fire suppression can be an advantageous practice for individuals who seek to protect homes, timber, and other assets in the short term. But over time, as flammable vegetation accumulates in a warming climate, suppressing fire across large areas can create risks of large-scale destructive wildfire events (Fischer et al., 2016; Moritz et al., 2014).

Because the adaptiveness of many forest management activities is relative to the ways in which landowners implement them, the goals they serve, and the spatial and temporal scales on which they are observed, rigorous approaches are needed for characterizing forest management activities in terms of adaptation behavior. To be valid in terms of adaptation behavior, forest management activities must be characterized in consistent, comparable, and coherent ways (Ford & Berrang-Ford, 2016).

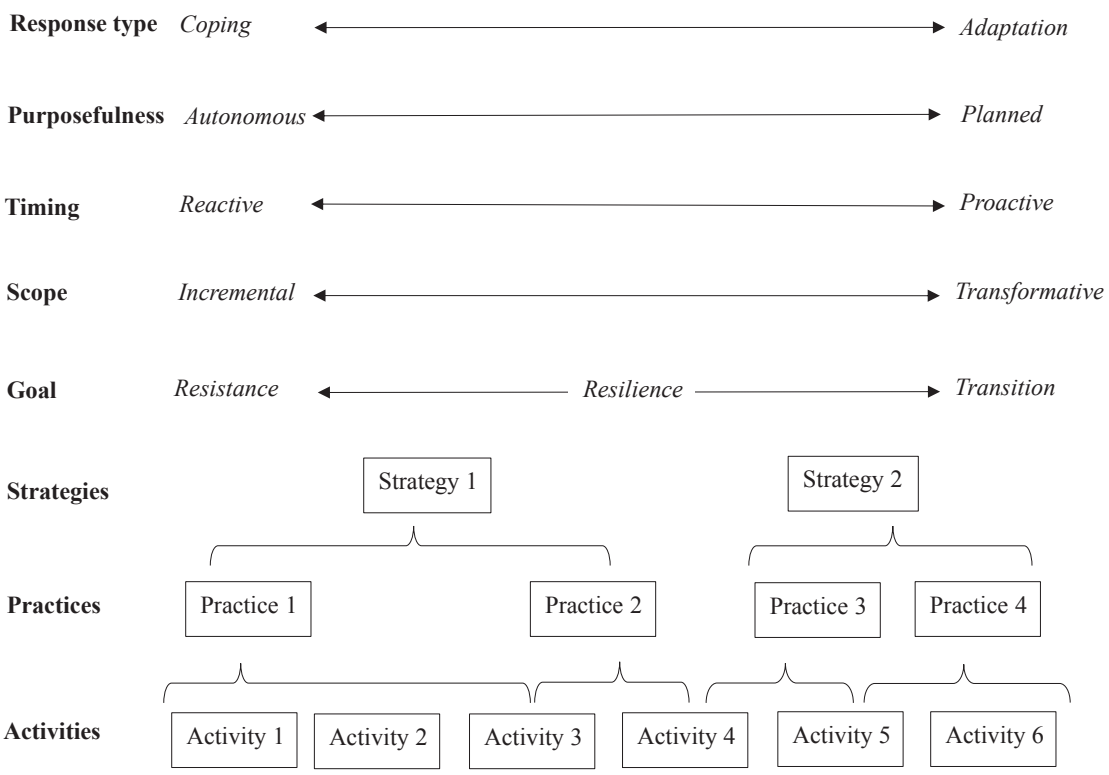

Fig. 1. Framework for characterizing behavioral adaptation climate change.

4. A more rigorous framework for characterizing behavioral adaptation to climate change

The framework I propose entails, as a first step, classifying behavioral responses to climate change into a hierarchy of three categories of behavior: activities, practices, and strategies (Fig. 1). Activities, and the practices they compose, are the most basic analytical units of social behavior (Schatzki, 1997). Practices are patterned and routinized behaviors driven by purposes or norms (Giddens, 1979, 1989; Reckwitz, 2002). Activities are the means through which people implement practices; their meaning derives from the rules and norms that govern the practices they compose (Schatzki, 1997). Individuals employ activities and practices as part of strategies, which are the mechanisms or processes governing the relationship between the practices and the goals they serve. In a second step, the framework entails characterizing behavioral strategies according to key attributes: purposefulness, timing, scope, and goals (Fig. 1). In a third step, the framework entails considering response strategies on a spectrum between coping and adaptation (Fig. 1).

In the context of temperate forests, the framework I propose refers to specific forest management treatments or interventions that individuals can undertake as activities. Activities can be active, such as thinning, harvesting, and fertilizing, or passive, such as not harvesting at the originally planned interval, where the absence of an intervention or treatment can be the activity. Activities can involve physically manipulating vegetation and soils, or they can involve other types of processes, such as planning or communication. Multiple activities compose a practice, such as controlling pests and diseases in a stand, which may involve activities such as spraying pesticides, pruning limbs, and thinning trees; reducing wildfire risk, which may involve pruning, thinning, harvesting, and burning excess vegetation; and coordinating management with neighbors, which may involve communicating at meetings and developing plans. Different practices can be composed of the same activities—for example, reducing the risk of wildfire on a forested property and reducing the susceptibility of a forested property to pests and diseases may both entail thinning. Practices can also entail activities that run counter to the purpose of another practice. For example, irrigating stands to reduce susceptibility to drought can also promote the growth of flammable vegetation that fuels wildfires.

Individuals employ practices as part of behavioral strategies. For example, as wildfires and pest and disease outbreaks become more expansive under future climate change, landowners may manage forests more strategically across larger areas by coordinating activities with neighbors, instead of managing independently on a parcel-by-parcel level (Fischer et al., This Issue). They may also develop longer-term plans to prepare to manage differently if conditions change (e.g., pests become worse). As such, they may exhibit planned and proactive adaptation rather than autonomous and reactive adaptation (Table 1). Managing on larger spatial scales may also be transformative if it involves the creation of new institutions for management. Alternatively, under expectations of higher temperatures and less precipitation, landowners may choose to reduce the probability and severity (risk) of stressors by thinning out dense trees and shrubs on their properties through which pests and diseases may spread and conducting controlled burns to keep their forests free from buildups of unhealthy vegetation. Such strategies would be characterized as autonomous, reactive, and incremental yet aimed at resilience. Landowners may also diversify species to create stands better suited to changing conditions (i.e., spreading risk). In this way, they may exhibit autonomous and proactive yet incremental adaptation, also aimed at resilience (Table 1). Alternatively, some landowners may prefer to prevent loss by doing everything possible to protect existing trees or species that are adapted to changing conditions (e.g., existing drought-adapted species). This would be an example of autonomous and proactive yet incremental adaptation, rather than reactive adaptation (Table 1). The attributes of behavioral strategies—purposefulness, timing, scope, and goals—reveal how individuals negotiate trade-offs associated with continuing to manage forests under new environmental conditions, altering the advantages and disadvantages of different types of adaptation behavior such that certain attributes become more beneficial while others

ARTICLE IN PRESS

become less so (Hamilton, Fischer, Guikema, & Keppel-Aleks, 2018). Landowners who undertake planned, proactive, and transformational responses to climate change may perceive that transitioning to new conditions will be more advantageous rather than resisting change (Table 1).

I argue that classifying climate change response behaviors by commensurate units within a hierarchy of behaviors and along dimensions of attributes of behavioral strategies would increase the consistency, comparability, and coherence—and therefore the overall rigor—of efforts to characterize behavioral responses to climate change. Clearly distinguishing between commensurate components of behavior—activities, practices, and strategies—makes it possible to focus on consistent and comparable variables that are important for evaluating adaptation coherently. Locating landowners' strategies along dimensions of purposefulness, timing, scope, and goals provides insight into the way they may be adapting to climate change, assuming they successfully reduce adverse impacts, take advantage of opportunities, and increase their suitability to new environmental conditions. In the case of temperate forests, landowners may engage in activities and practices as part of behavioral strategies that reflect autonomous, reactive, incremental, and resistant adaptation (e.g., preventing change in current forest conditions by reducing stress through fertilization and irrigation), as well as behavioral strategies that exhibit planned, proactive, transformative, and transitional adaptation behavior (e.g., coordinating with neighbors to manage forests on the large spatial and temporal scales on which stressors such as wildfire and pests and diseases occur) (Fig. 2). Characterizing adaptation in this way—in terms of sets of activities that compose practices that individuals use as part of strategies to pursue the goal of increased suitability to a changing environment—facilitates the identification of a nested set of variables that can be used to evaluate individual adaptation behavior. Moreover, applying such a framework to empirical research would help generate a comprehensive body of empirical data about individual adaptation to climate change, which would allow for comparison across different cases of climate change response.

The framework I propose could also help distinguish adaptation from coping. In the context of temperate forests, behaviors that exhibit adaptation could include adaptive management strategies that facilitate species migration, allow natural regeneration after disturbance, and increase ecosystem redundancy across the landscape (Janowiak et al., 2014; Keenan, 2015; Millar et al., 2007). These behaviors would fall toward the planned, proactive, transformational, and transition ends of the dimensions of purposefulness, timing, scope, and goals. Coping, on the other hand, could be exhibited by efforts to create refugia for rare species, harvest susceptible species before they succumb to disease, thin stands to prevent fire from ascending trees (Janowiak et al., 2014), and suppress wildfire, or create fuel breaks so fires cannot burn into stands (Spies et al., 2010). These behaviors would fall toward the autonomous, reactive, incremental, and resistance ends of the dimensions of purposefulness, timing, scope, and goals. In lieu of measuring outcomes of behavioral change (e.g., improved suitability), the goal, or intention, of a behavioral change can be used as an indicator of adaptation (Thomsen et al., 2012). For example, whether owners aim to be better off by thinning, or at least not be worse off, can be considered an indicator that their behavioral adjustment constitutes adaptation. Through strategies that reflect different dimensions of theoretical adaptation behavior, landowners exhibit their orientations around coping and adaptation: whether they are intending to reduce adverse impacts or learning to live under new conditions so they can be at least as well off, if not better off, in a changing climate (Fig. 2).

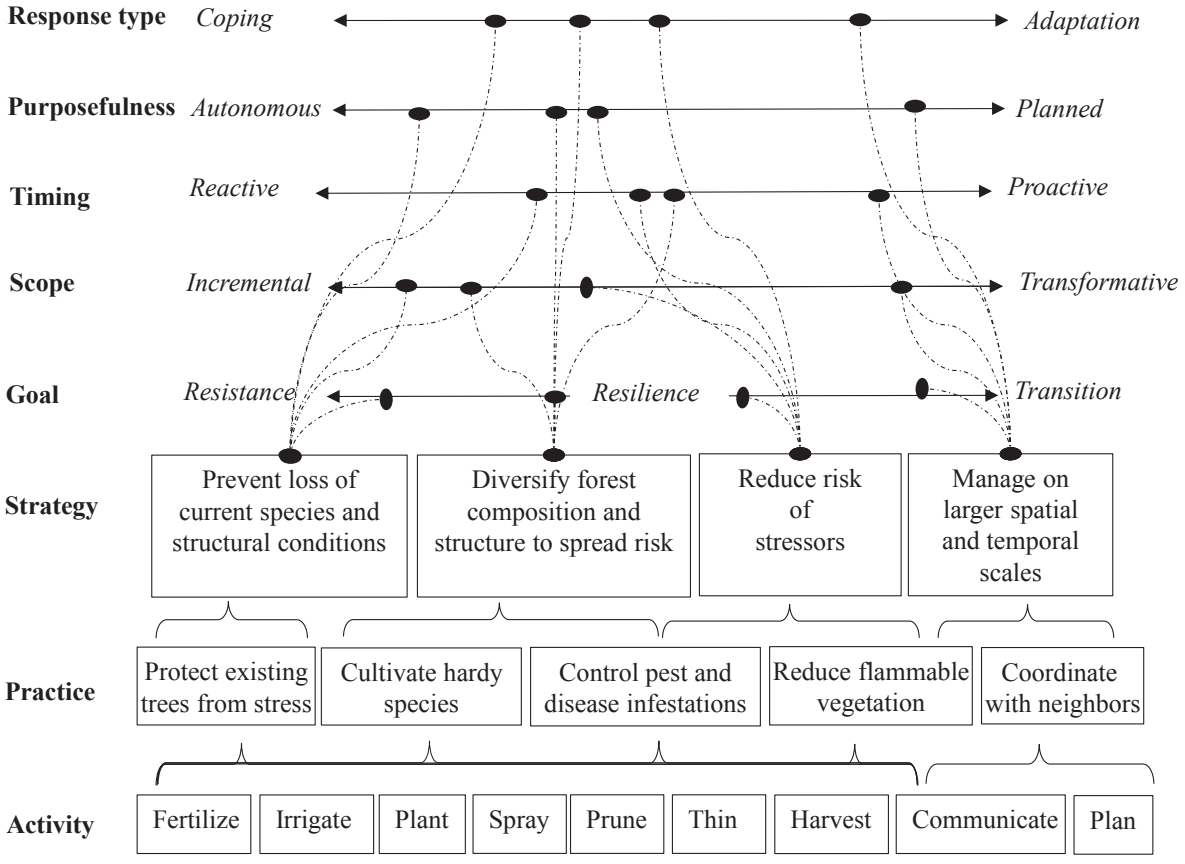

Fig. 2. Framework for characterizing behavioral adaptation climate change with examples from temperate forests.

ARTICLE IN PRESS

5. Conclusion

Drawing on current frameworks for characterizing adaptation to climate change, as well as empirical studies of how individuals have responded to climate change impacts, I have offered a framework for characterizing the responses of individuals in terms of adaptation behavior. The framework treats adaptation as a process of change in human behavior in response to change in the environment. The framework recognizes that, ultimately, determining whether behavioral responses are truly adaptive rests on evaluation of improvements in people's suitability to new environmental conditions. However, in lieu of such outcome measures, which must be gathered over time, adaptiveness can be evaluated on the basis of whether nested sets of activities, practices, and strategies that compose behavioral responses reduce adverse impacts in the near term or increase suitability to the environment over the long term. Only when activities and practices are considered in tandem with strategies can behavioral responses be characterized in terms of key attributes of adaptation behavior and located along the spectrum of coping and adaptation. Employing a framework such as this one reduces the chances of conflating adaptation with other types of responses to environmental change, such as coping, and increases the rigor of climate change adaptation research.

Frameworks such as the one I offer provide a structure for researchers and practitioners to investigate individual responses in consistent ways, by using commensurate and thus comparable categories and coherent definitions of adaptation. For example, the design of interview guides and survey questionnaires could draw on the framework and elicit data on people's practices (not just activities) and the strategies they use to reduce adverse impacts and take advantage of opportunities that come with climate change. Protocols for analysis could involve positioning these responses along dimensions of adaptation behavior to characterize their adaptiveness. Collecting and analyzing data in this way would provide a foundation for monitoring and cross-case comparison, which are critical for systematic and generalizable evaluations of adaptation. By increasing the consistency, comparability, and coherence of conceptualizations of adaptation, frameworks such as this one may improve the intellectual rigor and practical value of empirical research on behavioral responses to climate change.

Acknowledgements

I acknowledge support from USDA National Institute of Food and Agriculture McIntire Stennis project 1011135 and Forest Service Northern Research Station, and thank Matt Hamilton, Michal Russo, Aniseh Bro, and Garrett Powers for reviewing previous drafts of this article.

References

Allen, C. D., Macalady, A. K., Chenchouni, H., Bachelet, D., McDowell, N., Vennetier, M., ... Cobb, N. (2010). A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. *Forest Ecology and Management, 259*(4), 660–684.

Bachelet, D., Neilson, R. P., Hickler, T., Drapek, R. J., Lenihan, J. M., Sykes, M. T., ... Thonicke, K. (2003). Simulating past and future dynamics of natural ecosystems in the United States. *Global Biogeochemical Cycles, 17*(2), 1045. https://doi.org/10.1029/2001GB001508.

Barnett, J., & O'Neill, S. (2010). Maladaptation. *Global Environmental Change, 20*(2), 211–213. https://doi.org/10.1016/j.gloenvcha.2009.11.004.

Bassett, T. J., & Fogelman, C. (2013). Déjà vu or something new? The adaptation concept in the climate change literature. *Geoforum, 48*(Supplement C), 42–53. https://doi.org/10.1016/j.geoforum.2013.04.010.

Below, T. B., Mutabazi, K. D., Kirschke, D., Franke, C., Sieber, S., Siebert, R., & Tscherning, K. (2012). Can farmers' adaptation to climate change be explained by socio-economic household-level variables? *Global Environmental Change, 22*(1), 223–235. https://doi.org/10.1016/j.gloenvcha.2011.11.012.

Berrang-Ford, L., Ford, J. D., & Paterson, J. (2011). Are we adapting to climate change? *Global Environmental Change, 21*(1), 25–33. https://doi.org/10.1016/j.gloenvcha.2010.09.012.

Birkmann, J. (2011). First- and second-order adaptation to natural hazards and extreme events in the context of climate change. *Natural Hazards, 58*(2), 811–840. https://doi.org/10.1007/s11069-011-9806-8.

Blaikie, P., Cannon, T., Davis, I., & Wisner, B. (1994). *At risk: Natural hazards, people's vulnerability, and disasters.* London: Routledge.

Blennow, K. (2012). Adaptation of forest management to climate change among private individual forest owners in Sweden. *Forest Policy and Economics, 24*, 41–47. https://doi.org/10.1016/j.forpol.2011.04.005.

Blennow, K., & Persson, J. (2009). Climate change: Motivation for taking measure to adapt. *Global Environmental Change, 19*(1), 100–104. https://doi.org/10.1016/j.gloenvcha.2008.10.003.

Blennow, K., Persson, J., Tomé, M., & Hanewinkel, M. (2012). Climate change: Believing and Seeing Implies Adapting. *PLoS One, 7*(11), e50182. https://doi.org/10.1371/journal.pone.0050182.

Butler, B. J., & Leatherberry, E. C. (2004). Family forest owners of the western United States. *Journal of Forestry, 102*(8) 1 1.

Carpenter, S., Walker, B., Anderies, J. M., & Abel, N. (2001). From metaphor to measurement: Resilience of what to what? *Ecosystems, 4*(8), 765–781.

Chmura, D. J., Anderson, P. D., Howe, G. T., Harrington, C. A., Halofsky, J. E., Peterson, D. L., ... Brad St. Clair, J. (2011). Forest responses to climate change in the northwestern United States: Ecophysiological foundations for adaptive management. *Forest Ecology and Management, 261*(7), 1121–1142. https://doi.org/10.1016/j.foreco.2010.12.040.

Denevan, W. M. (1983). Adaptation, variation, and cultural geography. *The Professional Geographer, 35*(4), 399–407. https://doi.org/10.1111/j.0033-0124.1983.00399.x.

Dukes, J. S., Pontius, J., Orwig, D., Garnas, J. R., Rodgers, V. L., Brazee, N., ... Ayres, M. (2009). Responses of insect pests, pathogens, and invasive plant species to climate change in the forests of northeastern North America: What can we predict? *Canadian Journal of Forest Research, 39*(2), 231–248. https://doi.org/10.1139/X08-171.

Eriksson, L. (2014). Risk perception and responses among private forest owners in Sweden. *Small-scale Forest Economics, Management and Policy, 13*(4), 483–500. https://doi.org/10.1007/s11842-014-9266-6.

Esham, M., & Garforth, C. (2013). Agricultural adaptation to climate change: Insights from a farming community in Sri Lanka. *Mitigation and Adaptation Strategies for Global Change, 18*(5), 535–549. https://doi.org/10.1007/s11027-012-9374-6.

Fankhauser, S., Smith, J. B., & Tol, R. S. J. (1999). Weathering climate change: Some simple rules to guide adaptation decisions. *Ecological Economics, 30*(1), 67–78. https://doi.org/10.1016/S0921-8009(98)00117-7.

Fazey, I., Gamarra, J. G. P., Fischer, J., Reed, M. S., Stringer, L. C., & Christie, M. (2010). Adaptation strategies for reducing vulnerability to future environmental change. *Frontiers in Ecology and the Environment, 8*(8), 414–422. https://doi.org/10.1890/080215.

Fettig, C. J., Reid, M. L., Bentz, B. J., Sevanto, S., Spittlehouse, D. L., & Wang, T. (2013). Changing climates, changing forests: A western North American perspective. *Journal of Forestry, 111*(3), 214–228. https://doi.org/10.5849/jof.12-085.

Fischer, A. P. (in press). Adapting and coping with climate change in temperate forests. *Global Environmental Change.* https://doi.org/10.1016/j.gloenvcha.2018.10.011.

Fischer, A. P. (2011). Reducing hazardous fuels on nonindustrial private forests: Factors influencing landowner decisions. *Journal of Forestry, 109*(5), 260–266.

Fischer, A. P., Klooster, A., & Cirhigiri, L. (This Issue). Cross-boundary cooperation for landscape management: Collective action and social exchange among individual private forest landowners. *Landscape and Urban Planning.* doi:https://doi.org/10.1016/j.landurbplan.2018.02.004.

Fischer, A. P., & Frazier, T. G. (2018). Social vulnerability to climate change in temperate forest areas: New measures of exposure, sensitivity, and adaptive capacity. *Annals of the American Association of Geographers, 108*(3), 658–678. https://doi.org/10.1080/24694452.2017.1387046.

Fischer, A. P., Spies, T. A., Steelman, T. A., Moseley, C., Johnson, B. R., Bailey, J. D., ... Bowman, D. M. J. S. (2016). Wildfire risk as a socioecological pathology. *Frontiers in Ecology and the Environment, 14*(5), 276–284. https://doi.org/10.1002/fee.1283.

Flannigan, M., Cantin, A. S., de Groot, W. J., Wotton, M., Newbery, A., & Gowman, L. M. (2013). Global wildland fire season severity in the 21st century. *Forest Ecology and Management, 294*, 54–61. https://doi.org/10.1016/j.foreco.2012.10.022.

Ford, J. D., & Berrang-Ford, L. (2016). The 4Cs of adaptation tracking: Consistency, comparability, comprehensiveness, coherency. *Mitigation and Adaptation Strategies for Global Change, 21*(6), 839–859. https://doi.org/10.1007/s11027-014-9627-7.

Forest Europe. (2011). State of Europe's Forests 2011. Status and Trends in Sustainable Forest Management in Europe. Available from Aas, Norway: http://www.foresteurope.org.

Giddens, A. (1979). *Central problems in social theory.* Berkeley: University of California Press.

Giddens, A. (1989). *Constitution of society: Outline of the theory of structuration.* Berkeley: University of California Press.

Gómez-Mendoza, L., & Galicia, L. (2010). Temperate forests and climate change in Mexico: From modelling to adaptation strategies. In S. Simard (Ed.). *Climate change and variability* (pp. 195–209). Rijeka, Croatia: Intech.

Grothmann, T., & Patt, A. (2005). Adaptive capacity and human cognition: The process of individual adaptation to climate change. *Global Environmental Change, 15*(3), 199–213.

Grotta, A. T., Creighton, J. H., Schnepf, C., & Kantor, S. (2013). Family forest owners and climate change: Understanding, attitudes, and educational needs. *Journal of Forestry, 111*(2), 87–93. https://doi.org/10.1038/nclimate1542.

Hamilton, M., Fischer, A. P., Guikema, S. D., & Keppel-Aleks, G. (2018). Behavioral adaptation to climate change in wildfire-prone forests. *Wiley Interdisciplinary Reviews: Climate Change, 9*(6), e553. https://doi.org/10.1002/wcc.553.

ARTICLE IN PRESS

Hanewinkel, M., Cullmann, D. A., Schelhaas, M.-J., Nabuurs, G.-J., & Zimmermann, N. E. (2013). Climate change may cause severe loss in the economic value of European forest land. *Nature Climate Change, 3*(3), 203.

Hayhoe, K., VanDorn, J., Croley Ii, T., Schlegal, N., & Wuebbles, D. (2010). Regional climate change projections for Chicago and the US Great Lakes. *Journal of Great Lakes Research, 36*(Supplement 2), 7–21. https://doi.org/10.1016/j.jglr.2010.03.012.

Hubbart, J. A., Guyette, R., & Muzika, R.-M. (2016). More than drought: Precipitation variance, excessive wetness, pathogens and the future of the western edge of the eastern deciduous forest. *Science of The Total Environment, 566–567*, 463–467. https://doi.org/10.1016/j.scitotenv.2016.05.108.

Irland, L. C., Adams, D., Alig, R., Betz, C. J., Chen, C.-C., Hutchins, M., ... Sohngen, B. L. (2001). Assessing socioeconomic impacts of climate change on US forests, wood-product markets, and forest recreation. *BioScience, 51*(9), 753–764. https://doi.org/10.1641/0006-3568(2001) 051[0753:asiocc]2.0.co;2.

Janowiak, M. K., Swanston, C. W., Nagel, L. M., Brandt, L. A., Butler, P. R., Handler, S. D., ... Peters, M. P. (2014). A practical approach for translating climate change adaptation principles into forest management actions. *Journal of Forestry, 112*(5), 424–433. https://doi.org/10.5849/jof.13-094.

Jonsson, A. M., Appelberg, G., Harding, S., & Bärring, L. (2009). Spatio-temporal impact of climate change on the activity and voltinism of the spruce bark beetle, Ips typographus. *Global Change Biology, 15*(2), 486–499. https://doi.org/10.1111/j.1365-2486.2008.01742.x.

Juhola, S., Glaas, E., Linnér, B.-O., & Neset, T.-S. (2016). Redefining maladaptation. *Environmental Science & Policy, 55*(Part 1), 135–140. https://doi.org/10.1016/j.envsci.2015.09.014.

Kates, R. W., Travis, W. R., & Wilbanks, T. J. (2012). Transformational adaptation when incremental adaptations to climate change are insufficient. *Proceedings of the National Academy of Sciences, 109*(19), 7156–7161. https://doi.org/10.1073/pnas.1115521109.

Keenan, R. J. (2015). Climate change impacts and adaptation in forest management: A review. *Annals of Forest Science, 72*(2), 145–167. https://doi.org/10.1007/s13595-014-0446-5.

Kolström, M., Lindner, M., Vilén, T., Maroschek, M., Seidl, R., Lexer, M. J., ... Corona, P. (2011). Reviewing the science and implementation of climate change adaptation measures in European forestry. *Forests, 2*(4), 961.

Lal, P., Alavalapati, J. R., & Mercer, E. (2011). Socio-economic impacts of climate change on rural United States. *Mitigation and Adaptation Strategies for Global Change, 16*(7), 819–844. https://doi.org/10.1007/s11027-011-9295-9.

Lawrence, A., & Marzano, M. (2014). Is the private forest sector adapting to climate change? A study of forest managers in north Wales. *Annals of Forest Science, 71*(2), 291–300. https://doi.org/10.1007/s13595-013-0326-4.

Lidskog, R., & Sjödin, D. (2014). Why do forest owners fail to heed warnings? Conflicting risk evaluations made by the Swedish forest agency and forest owners. *Scandinavian Journal of Forest Research, 29*(3), 275–282. https://doi.org/10.1080/02827581.2014.910268.

Lin, B. B., & Petersen, B. (2013). Resilience, regime shifts, and guided transition under climate change: Examining the practical difficulties of managing continually changing systems. *Ecology and Society, 18*(1), https://doi.org/10.5751/es-05128-180128.

Liu, J. C., Pereira, G., Uhl, S. A., Bravo, M. A., & Bell, M. L. (2015). A systematic review of the physical health impacts from non-occupational exposure to wildfire smoke. *Environmental Research, 136*(Supplement C), 120–132. https://doi.org/10.1016/j.envres.2014.10.015.

Lopez-Marrero, T. (2010). An integrative approach to study and promote natural hazards adaptive capacity: A case study of two flood-prone communities in Puerto Rico. *Geographical Journal, 176*(2), 150–163. https://doi.org/10.1111/j.1475-4959.2010.00353.x.

Maracchi, G., Sirotenko, O., & Bindi, M. (2005). Impacts of present and future climate variability on agriculture and forestry in the temperate regions: Europe. *Climatic Change, 70*(1), 117–135. https://doi.org/10.1007/s10584-005-5939-7.

McCarthy, J. J., Canziani, O. F., Leary, N. A., Dokken, D. J., & White, K. S. (Eds.). (2001). *Climate change 2001: Impacts, adaptation, and vulnerability: Contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press.

Millar, C. I., & Stephenson, N. L. (2015). Temperate forest health in an era of emerging megadisturbance. *Science, 349*(6250), 823–826. https://doi.org/10.1126/science.aaa9933.

Millar, C. I., Stephenson, N. L., & Stephens, S. L. (2007). Climate change and forests of the future: Managing in the face of uncertainty. *Ecological Applications, 17*(8), 2145–2151. https://doi.org/10.1890/06-1715.1.

Moritz, M. A., Batllori, E., Bradstock, R. A., Gill, A. M., Handmer, J., Hessburg, P. F., ... Syphard, A. D. (2014). Learning to coexist with wildfire. *Nature, 515*(7525), 58–66. https://doi.org/10.1038/nature13946.

Nelson, D. R. (2011). Adaptation and resilience: Responding to a changing climate. *Wiley Interdisciplinary Reviews: Climate Change, 2*(1), 113–120. https://doi.org/10.1002/wcc.91.

Nelson, D. R., Adger, W. N., & Brown, K. (2007). Adaptation to environmental change: Contributions of a resilience framework. *Annual Review of Environment and Resources, 32*(1), 395–419. https://doi.org/10.1146/annurev.energy.32.051807.090348.

Ogden, A., & Innes, J. (2008). Climate change adaptation and regional forest planning in southern Yukon, Canada. *Mitigation and Adaptation Strategies for Global Change, 13*(8), 833–861. https://doi.org/10.1007/s11027-008-9144-7.

Opiyo, F., Wasonga, O., Nyangito, M., Schilling, J., & Munang, R. (2015). Drought adaptation and coping strategies among the Turkana pastoralists of Northern Kenya. *International Journal of Disaster Risk Science, 6*(3), 295–309. https://doi.org/10.1007/s13753-015-0063-4.

Park, S. E., Marshall, N. A., Jakku, E., Dowd, A. M., Howden, S. M., Mendham, E., & Fleming, A. (2012). Informing adaptation responses to climate change through theories of transformation. *Global Environmental Change, 22*(1), 115–126. https://doi.org/10.1016/j.gloenvcha.2011.10.003.

Parry, M. L., Canziani, O. F., Palutikof, J. P., P.J. van der Linden, & Hanson, C. E. (2007). Technical Summary. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Available from Cambridge, UK.

Pelling, M., O'Brien, K., & Matyas, D. (2015). Adaptation and transformation. *Climatic Change, 133*(1), 113–127. https://doi.org/10.1007/s10584-014-1303-0.

Peltola, H., Kellomäki, S., & Väisänen, H. (1999). Model computations of the impact of climatic change on the windthrow risk of trees. *Climatic Change, 41*(1), 17–36. https://doi.org/10.1023/a:1005399822319.

Raymond, C. M., & Robinson, G. M. (2013). Factors affecting rural landholders' adaptation to climate change: Insights from formal institutions and communities of practice. *Global Environmental Change, 23*(1), 103–114. https://doi.org/10.1016/j.gloenvcha.2012.11.004.

Reams, M. A., Haines, T. K., Renner, C. R., Wascom, M. W., & Kingre, H. (2005). Goals, obstacles and effective strategies of wildfire mitigation programs in the Wildland-Urban Interface. *Forest Policy and Economics, 7*(5), 818–826. https://doi.org/10.1016/j.forpol.2005.03.006.

Reckwitz, A. (2002). Toward a theory of social practices: A development in culturalist theorizing. *European Journal of Social Theory, 5*(2), 243–263. https://doi.org/10.1177/13684310222225432.

Schatzki, T. R. (1997). Practices and actions A Wittgensteinian critique of Bourdieu and Giddens. *Philosophy of the Social Sciences, 27*(3), 283–308. https://doi.org/10.1177/004839319702700301.

Schoene, D. H. F., & Bernier, P. Y. (2012). Adapting forestry and forests to climate change: A challenge to change the paradigm. *Forest Policy and Economics, 24*, 12–19. https://doi.org/10.1016/j.forpol.2011.04.007.

Seidl, R., Thom, D., Kautz, M., Martin-Benito, D., Peltoniemi, M., Vacchiano, G., ... Honkaniemi, J. (2017). Forest disturbances under climate change. *Nature Climate Change, 7*(6), 395–402.

Smit, B., Burton, I., Klein, R. J. T., & Street, R. (1999). The science of adaptation: A framework for assessment. *Mitigation and Adaptation Strategies for Global Change, 4*(3), 199–213. https://doi.org/10.1023/a:1009652531101.

Smit, B., Burton, I., Klein, R. J. T., & Wandel, J. (2000). An anatomy of adaptation to climate change and variability. *Climatic Change, 45*(1), 223–251. https://doi.org/10.1023/a:1005661622966.

Smit, B., & Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change, 16*(3), 282–292. https://doi.org/10.1016/j.gloenvcha.2006.03.008.

Sousa-Silva, R., Ponette, Q., Verheyen, K., Van Herzele, A., & Muys, B. (2016). Adaptation of forest management to climate change as perceived by forest owners and managers in Belgium. *Forest Ecosystems, 3*(1), 22. https://doi.org/10.1186/s40663-016-0082-7.

Spies, T., Giesen, T., Swanson, F., Franklin, J., Lach, D., & Johnson, K. (2010). Climate change adaptation strategies for federal forests of the Pacific Northwest, USA: Ecological, policy, and socio-economic perspectives. *Landscape Ecology, 25*(8), 1185–1199. https://doi.org/10.1007/s10980-010-9483-0.

Spittlehouse, D. L., & Stewart, R. B. (2003). Adaptation to climate change in forest management. *BC Journal of Ecosystems and Management, 4*(1), 1–11.

Swanston, C. W. J., Maria, K., Brandt, L. A., Butler, P. R., Handler, S. D., Shannon, P. D. … Darling, L. (2016). Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers. Available from Newtown Square, PA: https://doi.org/10.2737/NRS-GTR-87-2.

Thomsen, D. C., Smith, T. F., & Keys, N. (2012). Adaptation or manipulation? Unpacking climate change response strategies. *Ecology and Society, 17*(3), https://doi.org/10.5751/ES-04953-170320.

van Gameren, V., & Zaccai, E. (2015). Private forest owners facing climate change in Wallonia: Adaptive capacity and practices. *Environmental Science & Policy, 52*, 51–60. https://doi.org/10.1016/j.envsci.2015.05.004.

Walker, B., Carpenter, S., Anderies, J., Abel, N., Cumming, G., Janssen, M., ... Pritchard, R. (2002). Resilience management in social-ecological systems: A working hypothesis for a participatory approach. *Conservation Ecology, 6*(1), 14.

Wamsler, C., & Brink, E. (2014). Moving beyond short-term coping and adaptation. *Environment and Urbanization, 26*(1), 86–111. https://doi.org/10.1177/0956247813516061.

Wheeler, S., Zuo, A., & Bjornlund, H. (2013). Farmers' climate change beliefs and adaptation strategies for a water scarce future in Australia. *Global Environmental Change, 23*(2), 537–547. https://doi.org/10.1016/j.gloenvcha.2012.11.008.

Wise, R. M., Fazey, I., Stafford Smith, M., Park, S. E., Eakin, H. C., Archer Van Garderen, E. R. M., & Campbell, B. (2014). Reconceptualising adaptation to climate change as part of pathways of change and response. *Global Environmental Change, 28*, 325–336. https://doi.org/10.1016/j.gloenvcha.2013.12.002.

Woodruff, S. C., & Stults, M. (2016). Numerous strategies but limited implementation guidance in US local adaptation plans. *Nature Climate Change, advance online publication*. https://doi.org/10.1038/nclimate3012.

Zheng, Y., & Dallimer, M. (2016). What motivates rural households to adapt to climate change? *Climate and Development, 8*(2), 110–121. https://doi.org/10.1080/17565529.2015.1005037.